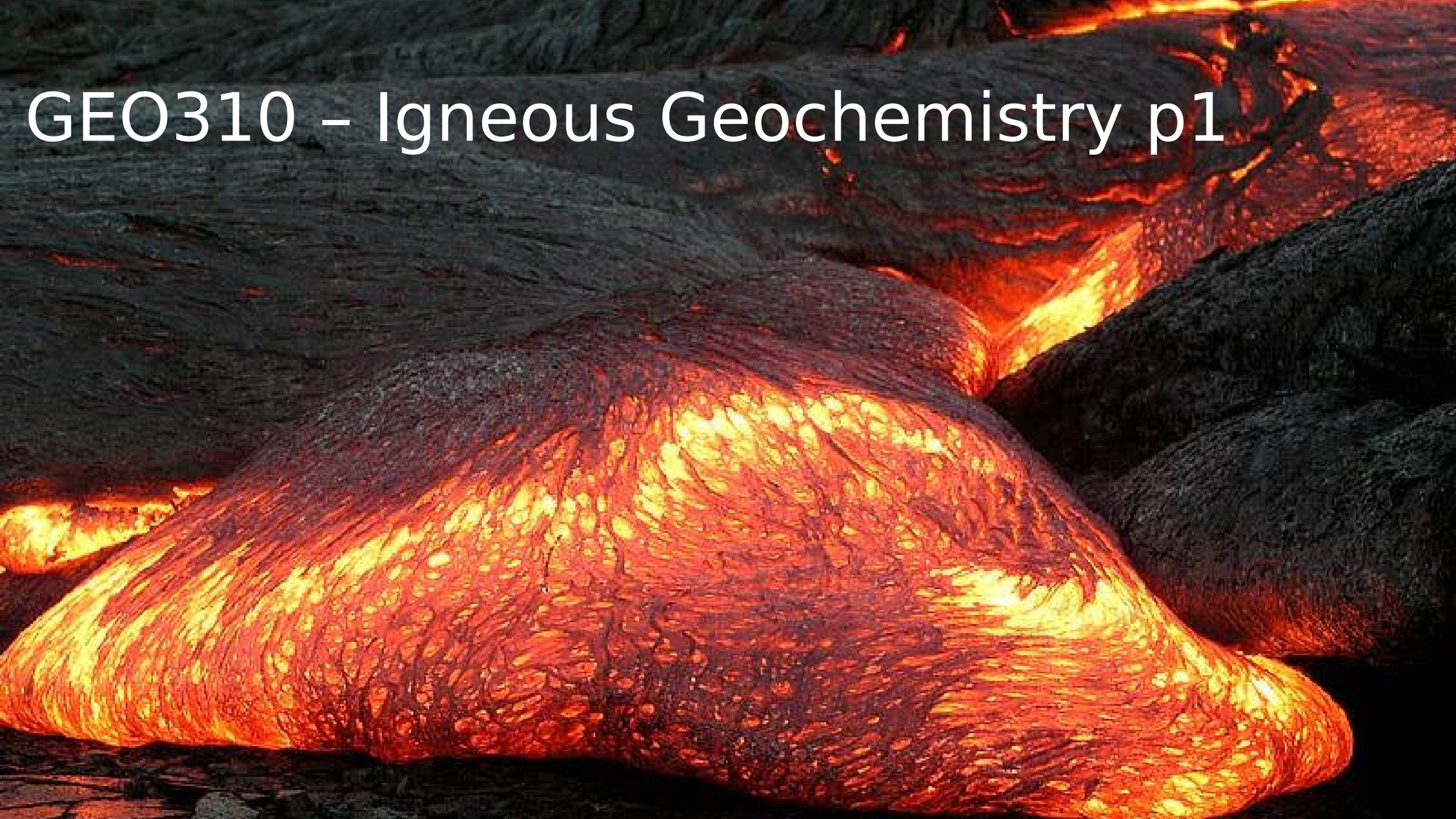
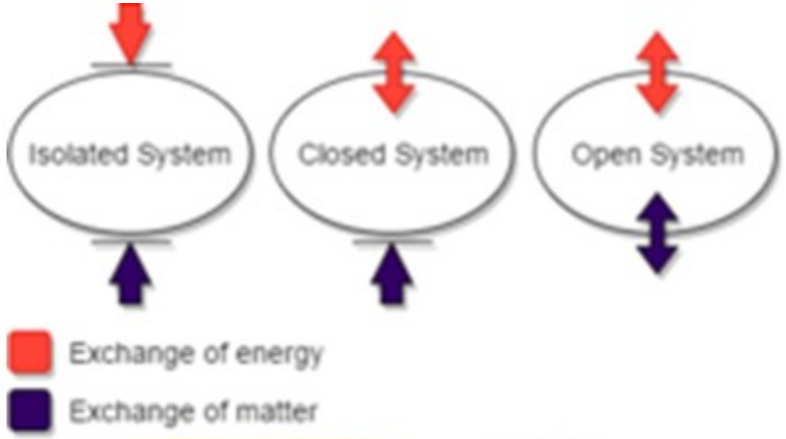
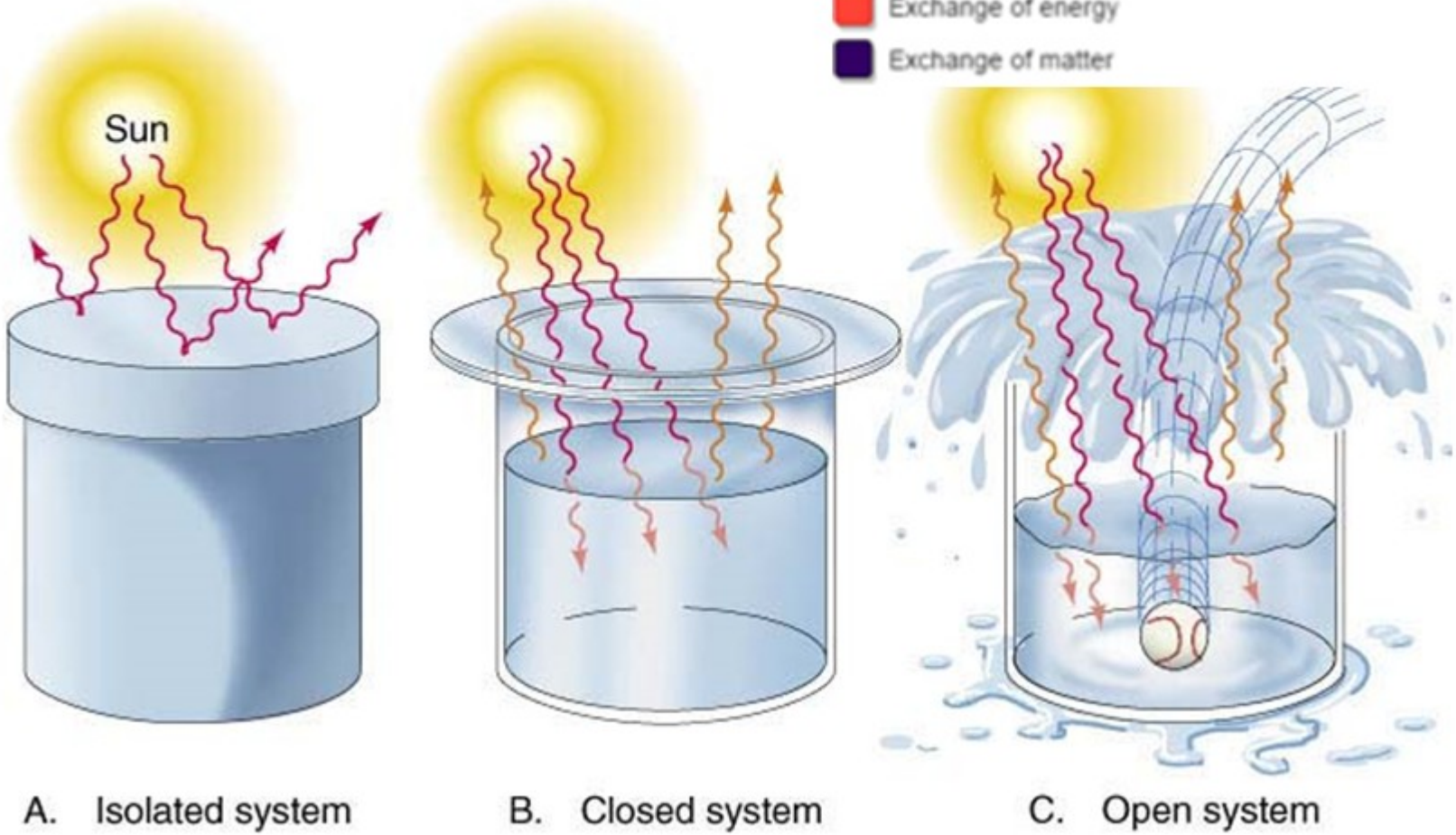
GEO310 – Igneous Geochemistry p1

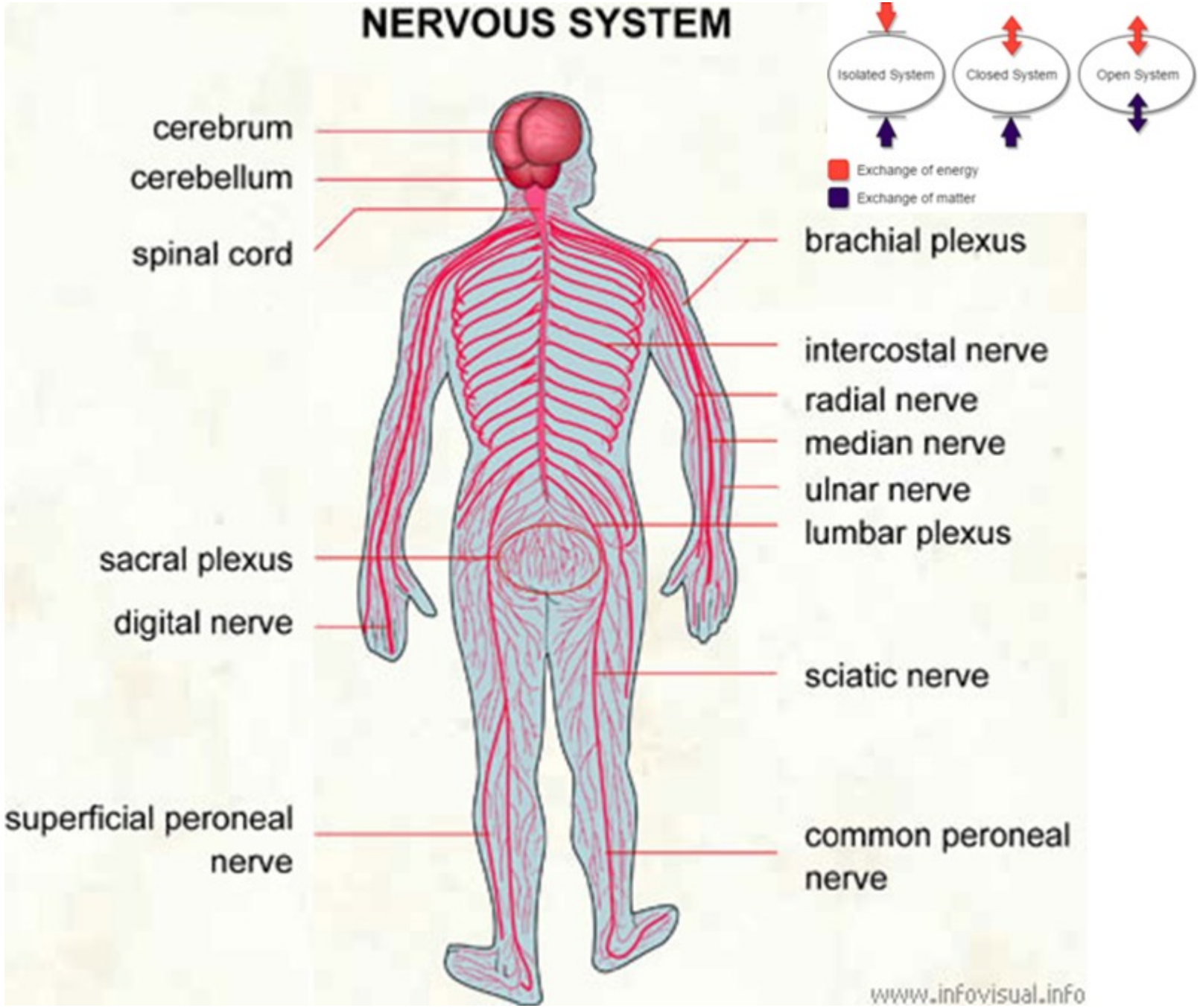


Systems Review

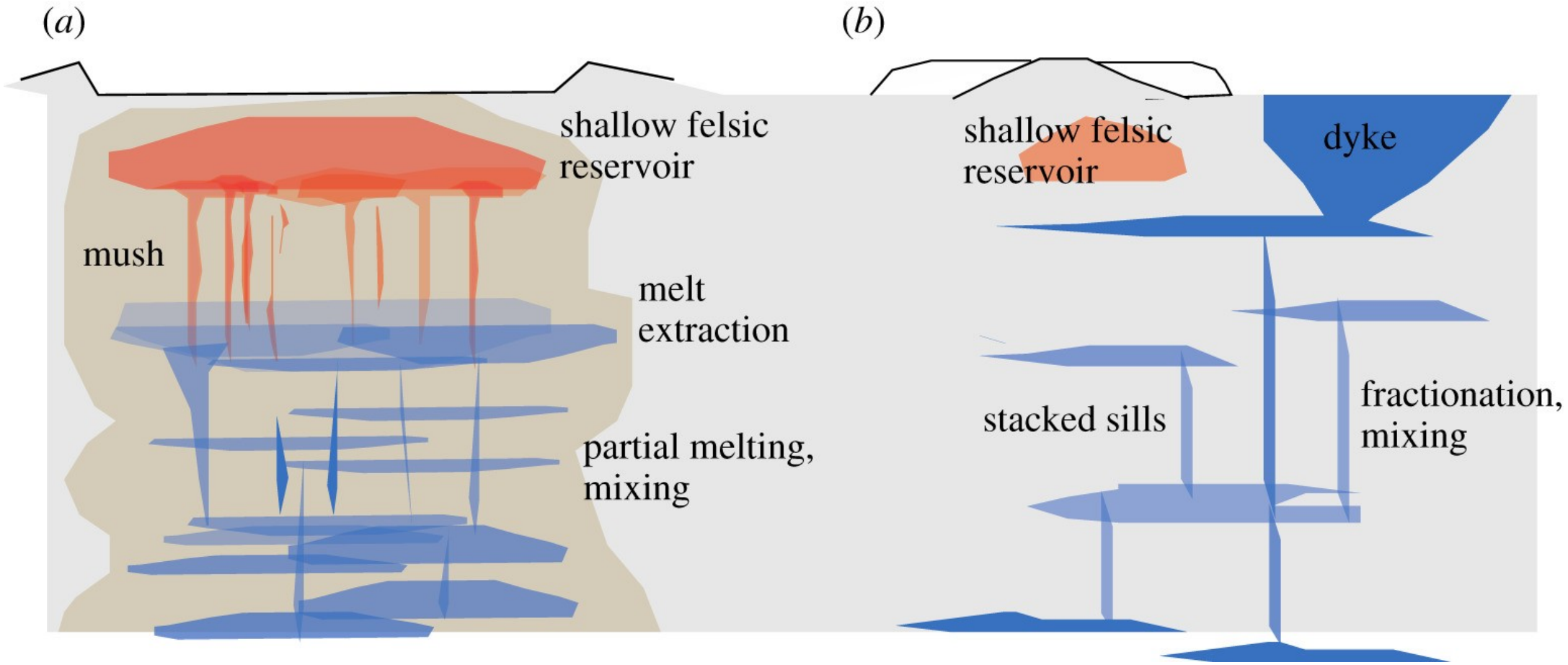




A. Isolated system B. Closed system C. Open system

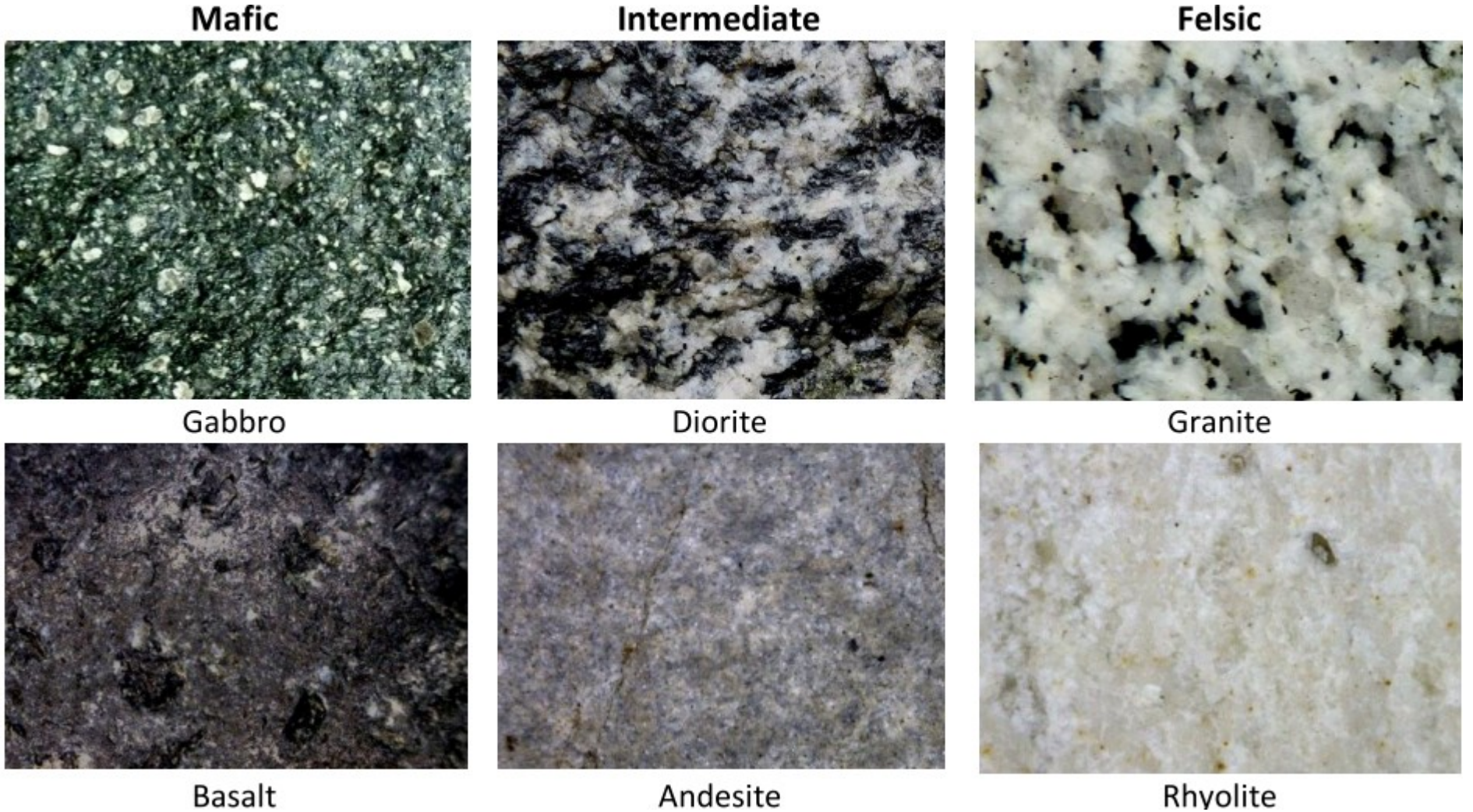

NERVOUS SYSTEM
cerebrum
cerebellum
spinal cord
sacral plexus
digital nerve
superficial peroneal nerve
brachial plexus
intercostal nerve
radial nerve
median nerve
ulnar nerve
lumbar plexus
sciatic nerve
common peroneal nerve
Isolated System
Closed System
Open System
Exchange of energy
Exchange of matter
www.infovisual.info

Igneous Systems – magmatic + volcanic



Edmonds et al., 2019

What geochemistry groups have you encountered before?



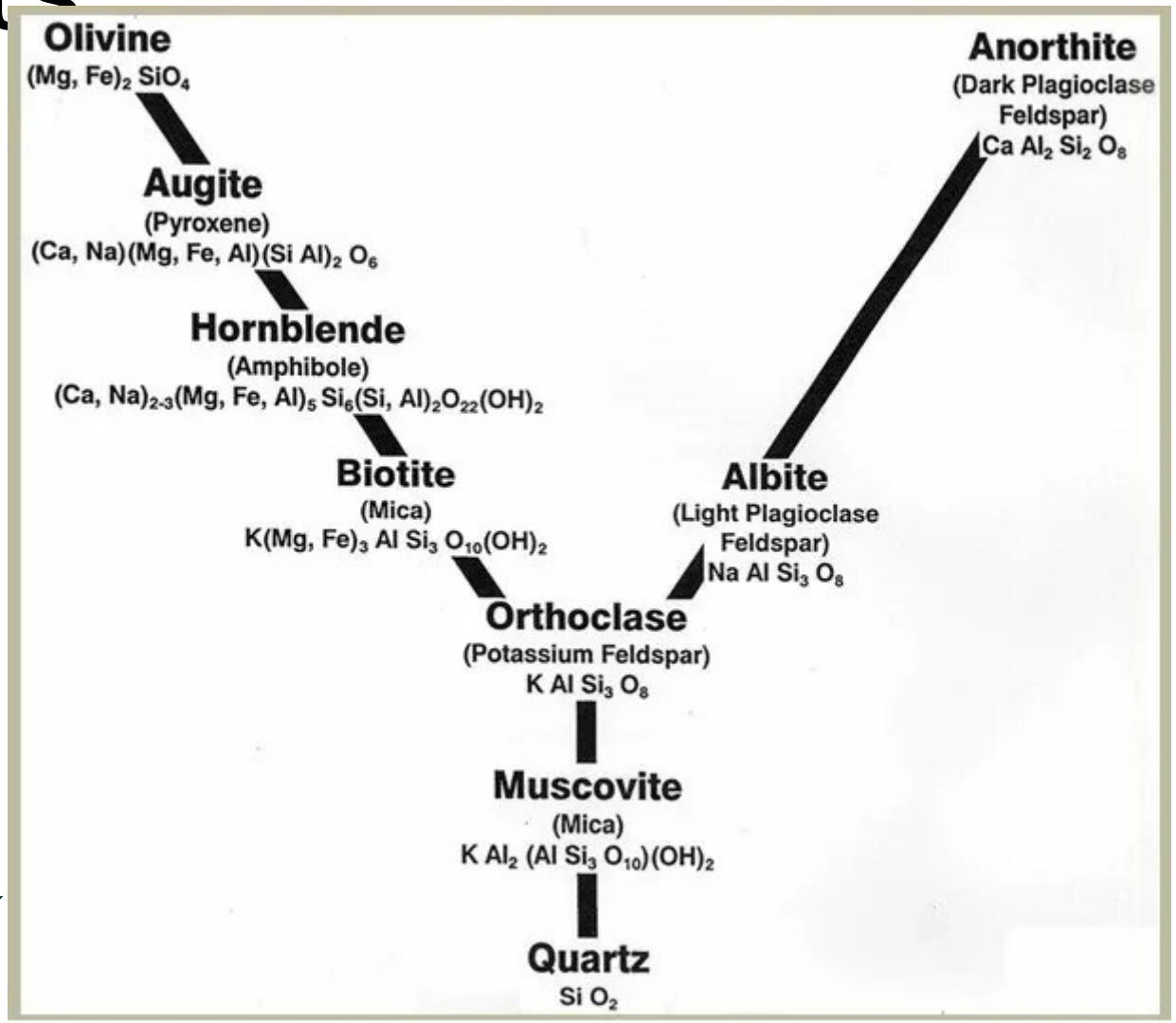
What are the most common rock forming minerals on Earth?

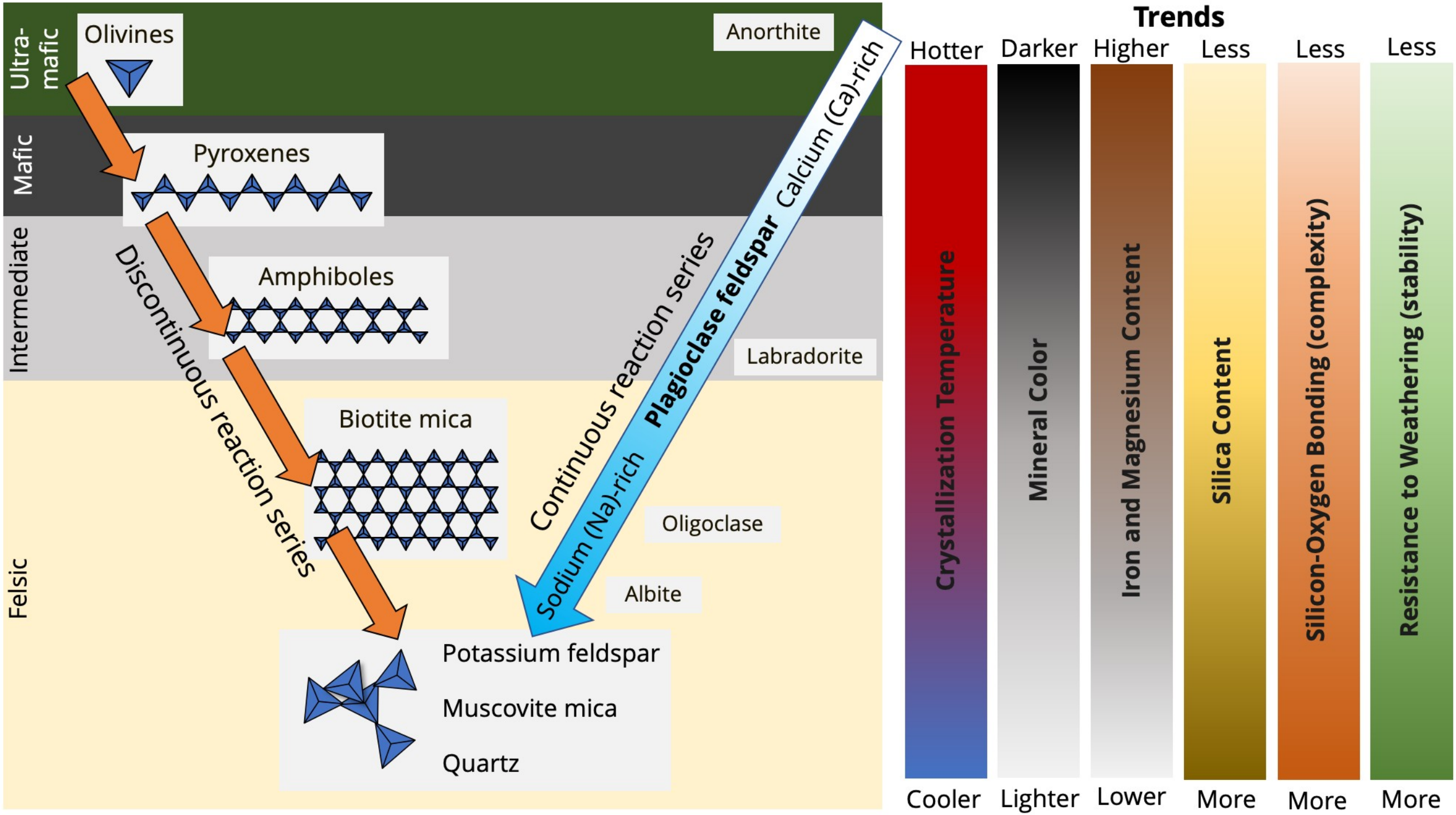
- Quartz
- Feldspar
- Micas & Clays (minor)
- Olivine
- Calcite (minor)
- Pyroxene
- Amphibole

Origin of Geochemistry – 1920s Bowen experiments

Tuttle (L) and Bowen (R) with furnaces, 1951

Temperature

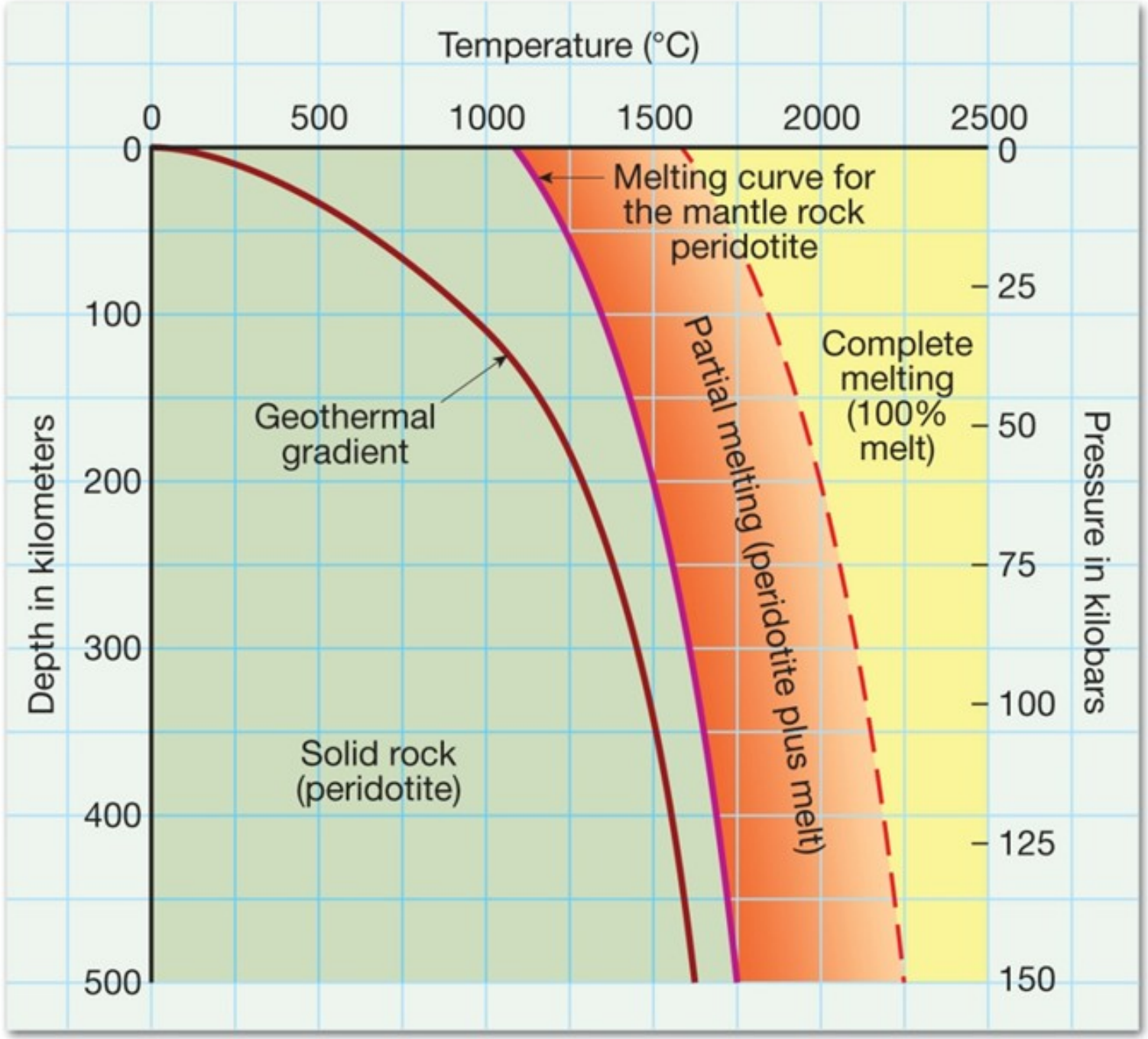



Ultra-mafic
Olivines
Anorthite
Mafic
Pyroxenes
Intermediate
Amphiboles
Labradorite
Discontinuous reaction series
Continuous reaction series
Plagioclase feldspar
Calcium (Ca)-rich
Sodium (Na)-rich
Biotite mica
Oligoclase
Felsic
Albite
Potassium feldspar
Muscovite mica
Quartz
Trends
Hotter
Darker
Higher
Less
Less
Less
Crystallization Temperature
Mineral Color
Iron and Magnesium Content
Silica Content
Silicon-Oxygen Bonding (complexity)
Resistance to Weathering (stability)
Cooler
Lighter
Lower
More
More
More

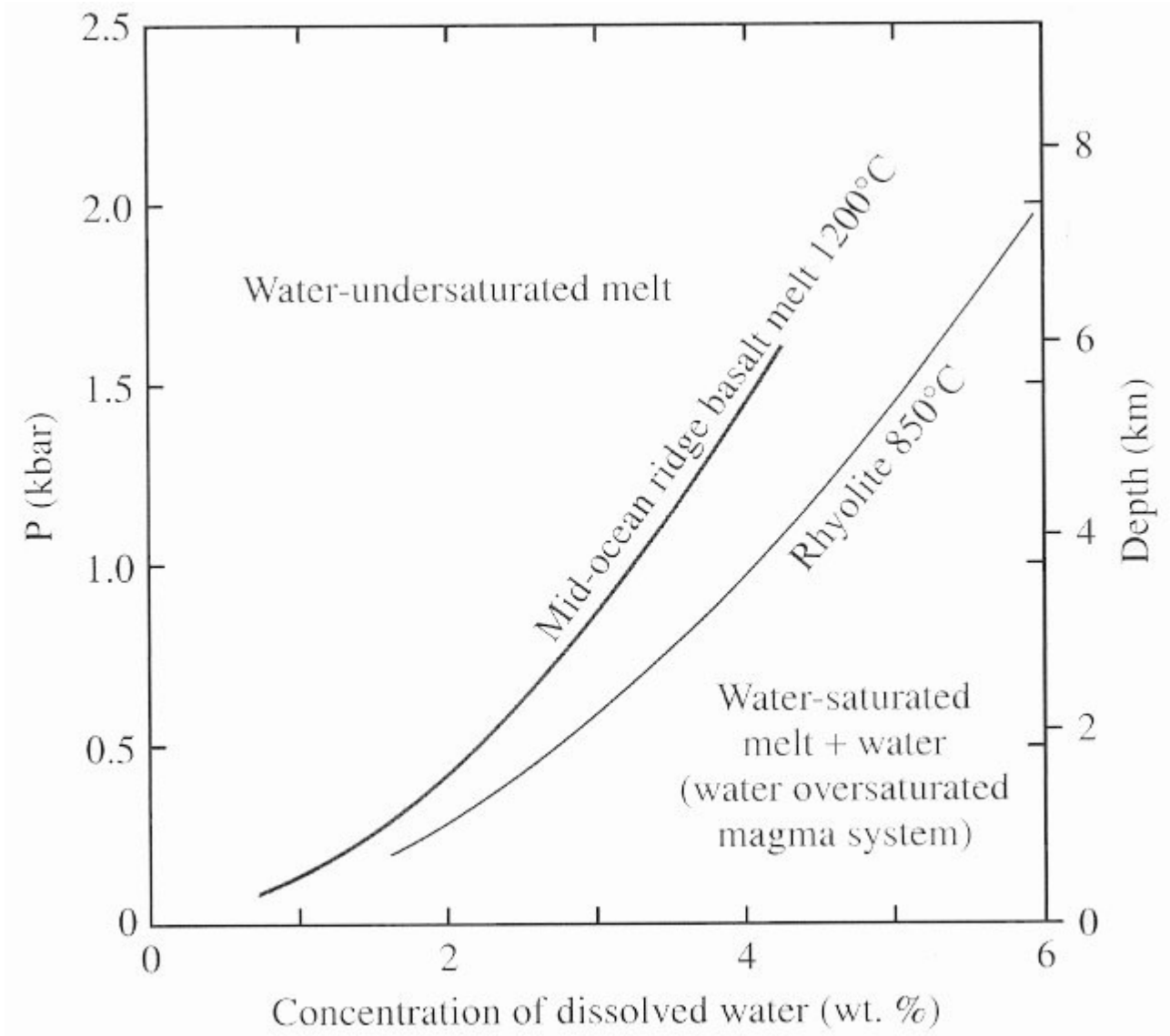
Thermodynamics – physical chemistry and the study of phase changes <3

- 3 ways to change phases (melt or crystallize)

- Changing the temperature
- Changing the pressure
- Changing the chemistry
  - (e.g. addition removal of H_2O is enormously impactful!)



© 2011 Pearson Education, Inc.



Solubility of water and its relation to pressure

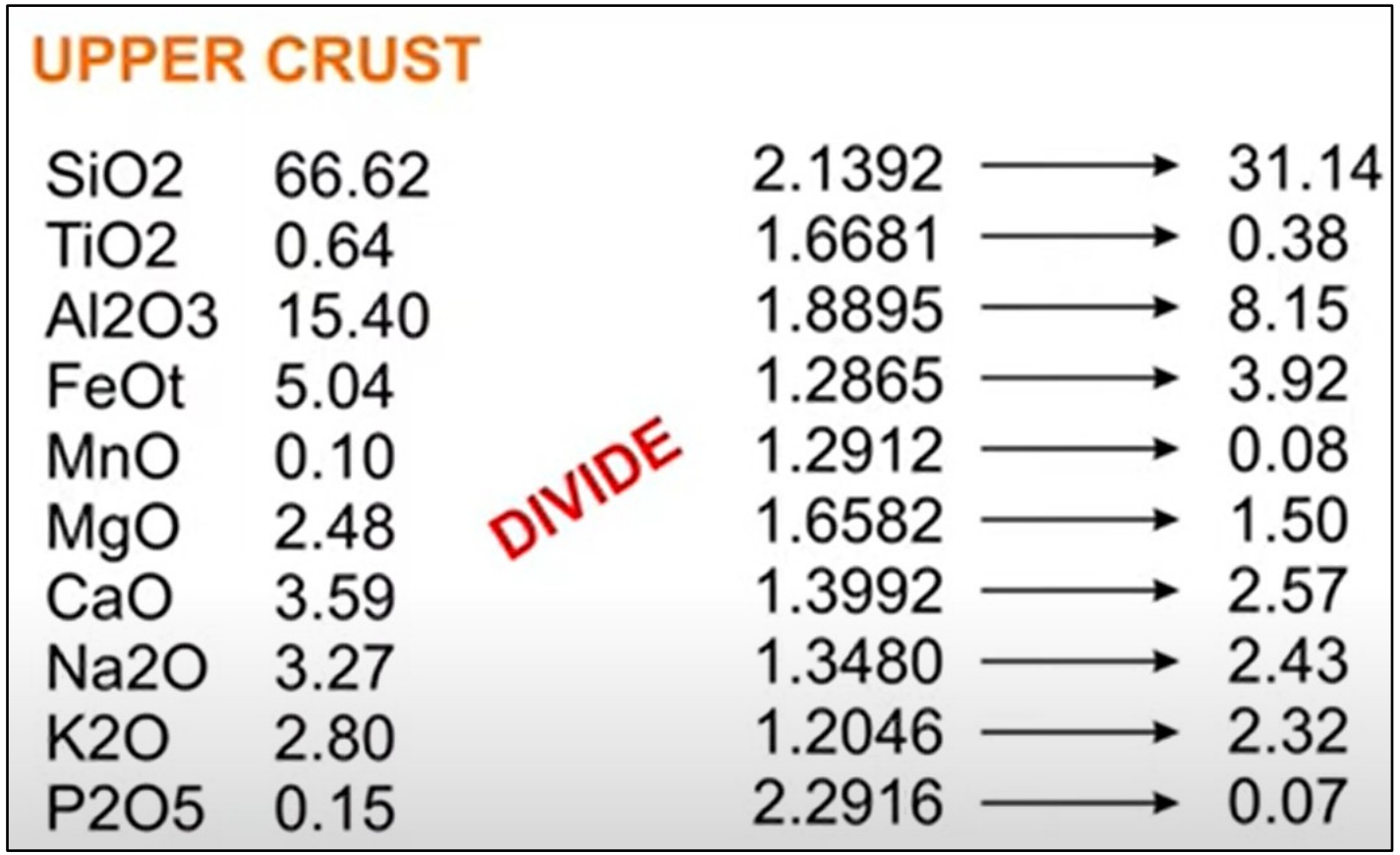
Next level geochemical groups - definitions

- **Major elements**: >1 wt. % of rocks
  - Si, Mg, Fe, Ca, Al, Na
- **Minor elements**: 0.1-1 wt. % of rocks
  - Ti, Mn, P, C, S, Cr
- **Trace elements**: < 0.1 wt. % - reported as ppm or ppb
- **Mode**: Visual determination of mineral abundances
- **Norm**: Quantified idealized mineralogy based on the rock composition (CIPW)

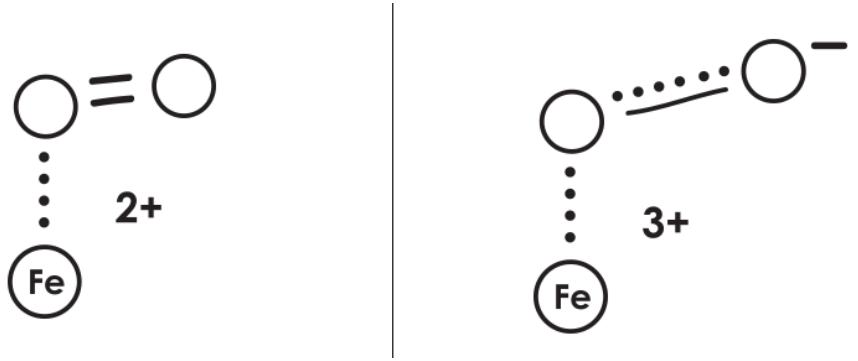
Reporting chemistry of earth materials

- Major and minor elements typically reported as oxides:

- Take the molecular weight of oxide
  - E.g. Mg = 24.3 at; O = 15.9 at.
  - MgO = 40.304
  - 40.3/24.3 = 1.6582



A note on iron



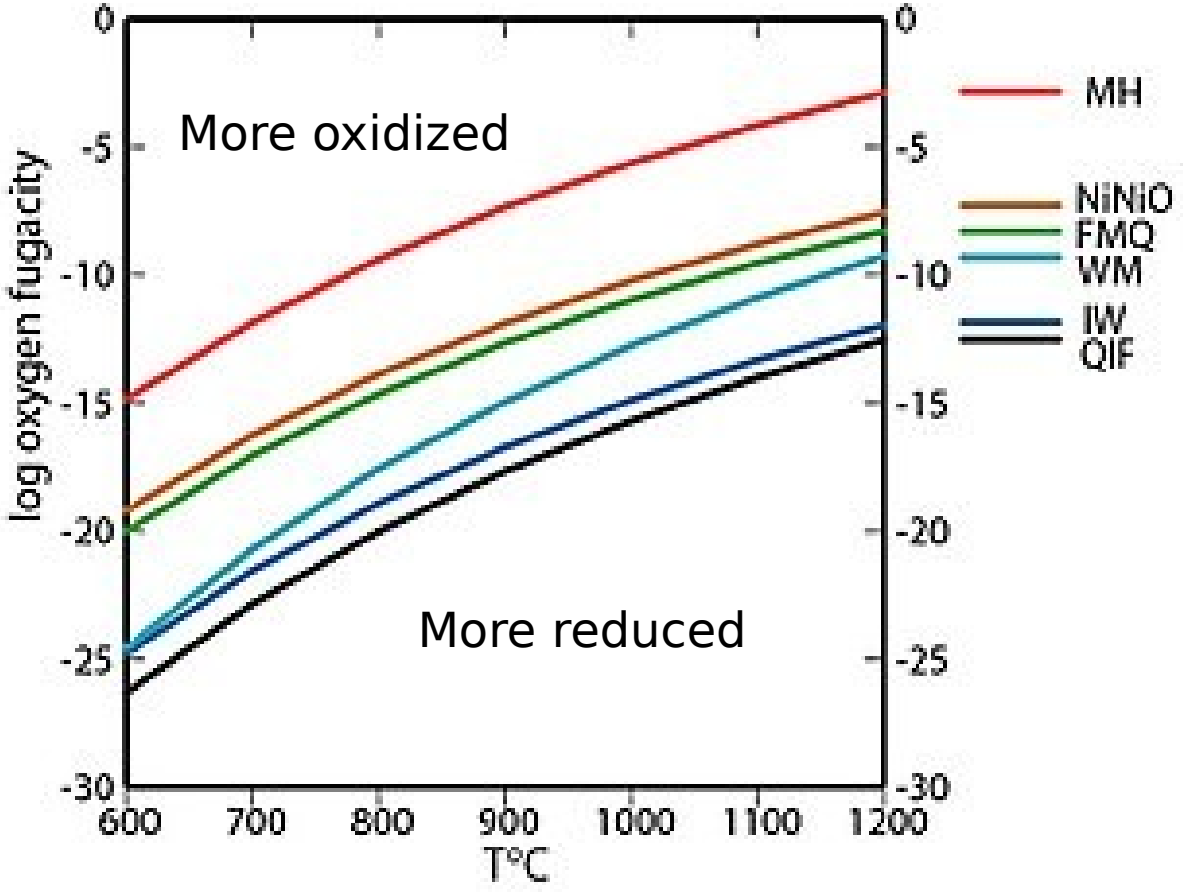
- Fe exists in two valence states:
  - Fe2+ Ferrous iron (FeO) more reduced
  - Fe3+ Ferric iron (Fe2O3) more oxidized
- Oxidation state important!!
- Fe can be reported as: Fe, FeO, FeOt, Fe2O3, Fe2O3t
- Need to know the redox conditions of the magma system to determine concentrations of each iron species

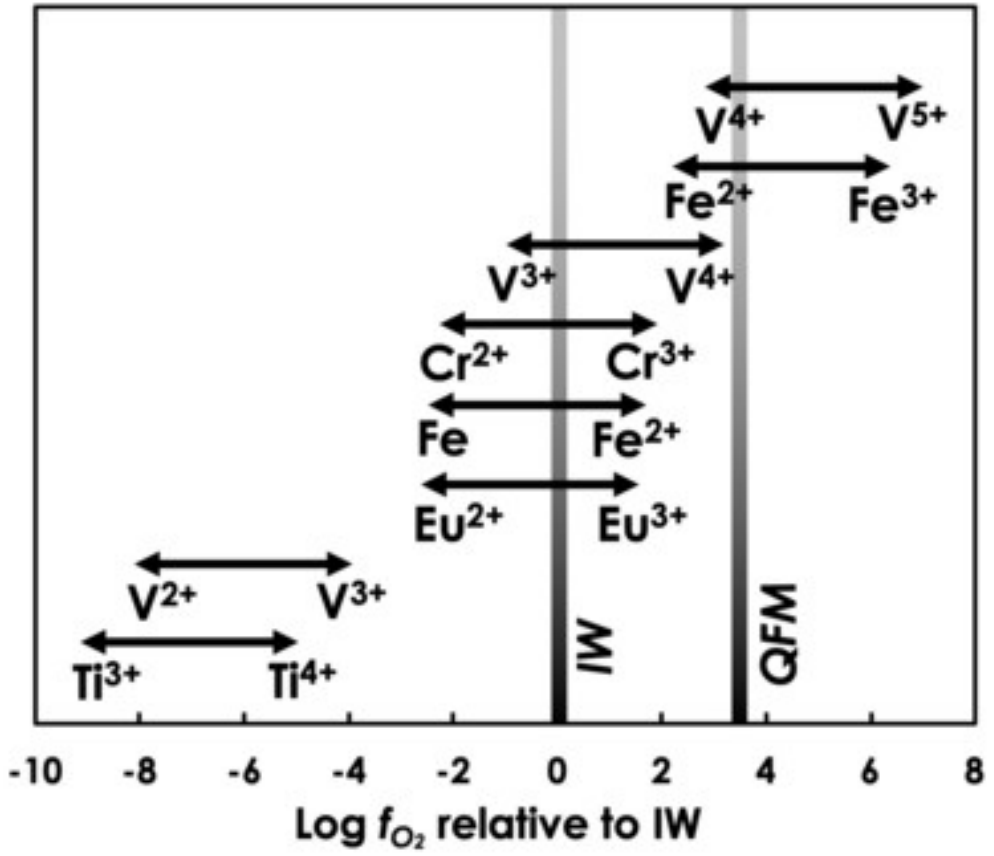
mol. % FeO = 71.85
mol. % Fe2O3 = 159.7

(2 x 71.85) / 159.7 = 0.899 (1/0.899 = 1.1113)

So FeO of 11.5 wt.%
11.5 / 0.899 = 12.78 wt.% Fe2O3v (v = true)

Oxygen Fugacity (fO_2) = describes the potential to be oxidized by oxygen (P/T dependent)





Shearer et al., (2006)

Geochemical analyses instruments

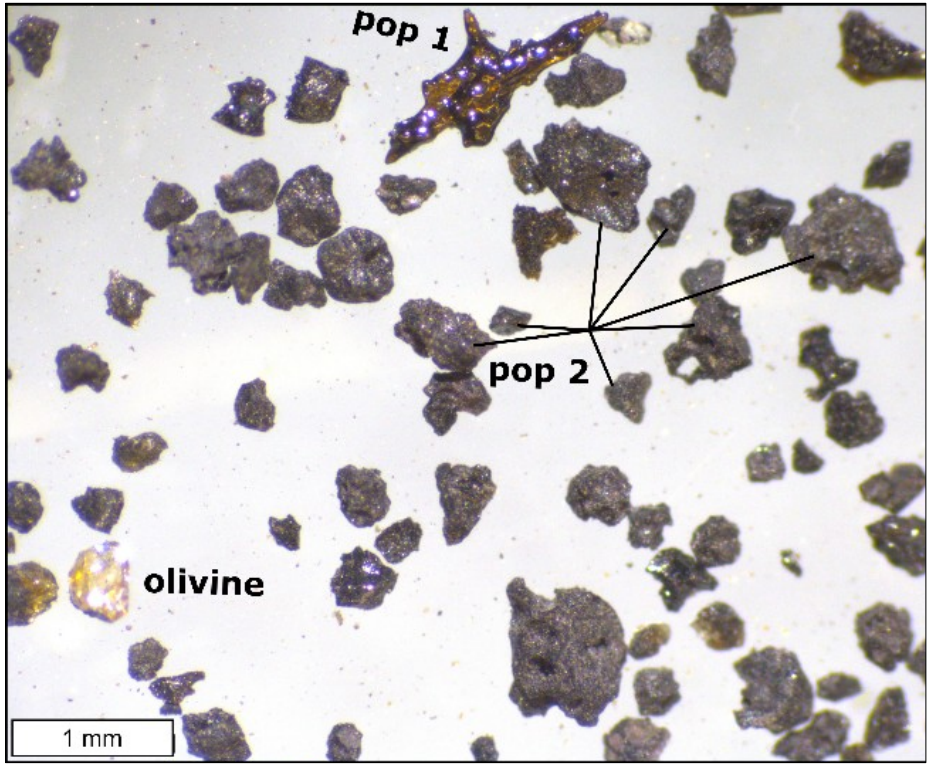
- Transmitted light microscope
- Energy beam instruments
  - X-ray instruments (XRD, XRF, XANES)
  - Electron beam instruments (SEM, EPMA)
  - Ion beam instrument (SIMS)
  - Infrared instrument (FTIR)
  - Lazers (LA-ICP-MS)

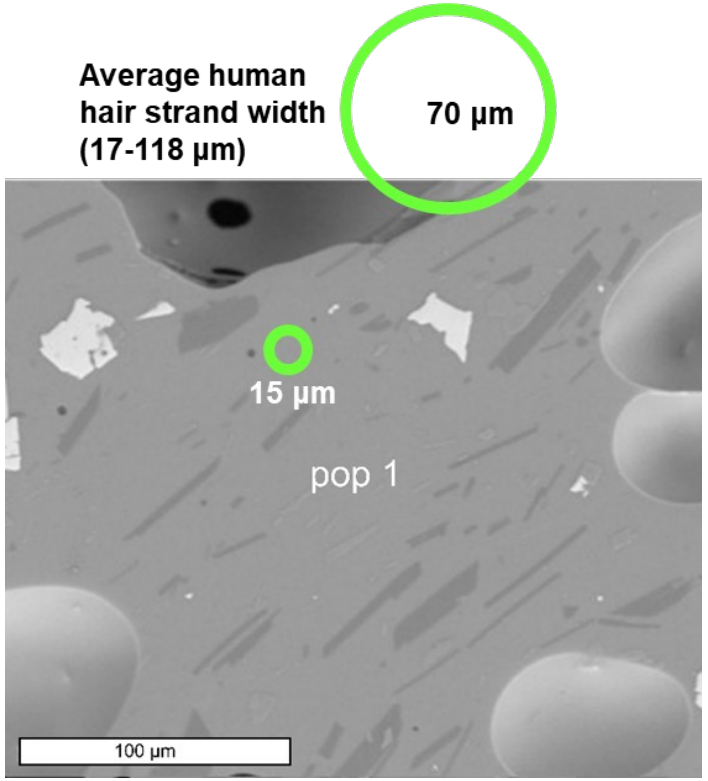
Types of igneous materials for study

Bulk Rock (instruments: XRF, XRD)

Types of igneous materials for study

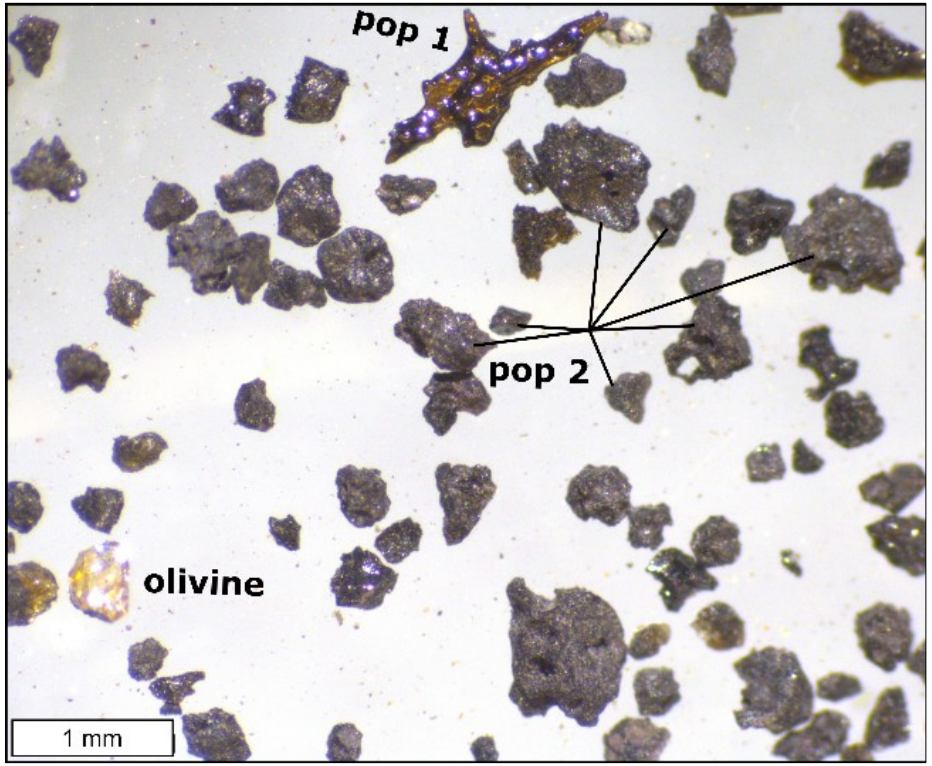
Matrix glass (instruments: EPMA, SEM, SIMS, FTIR, LA-ICP-MS)

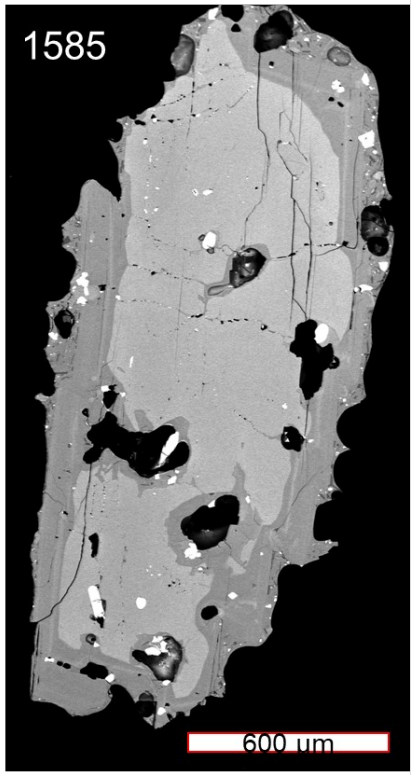


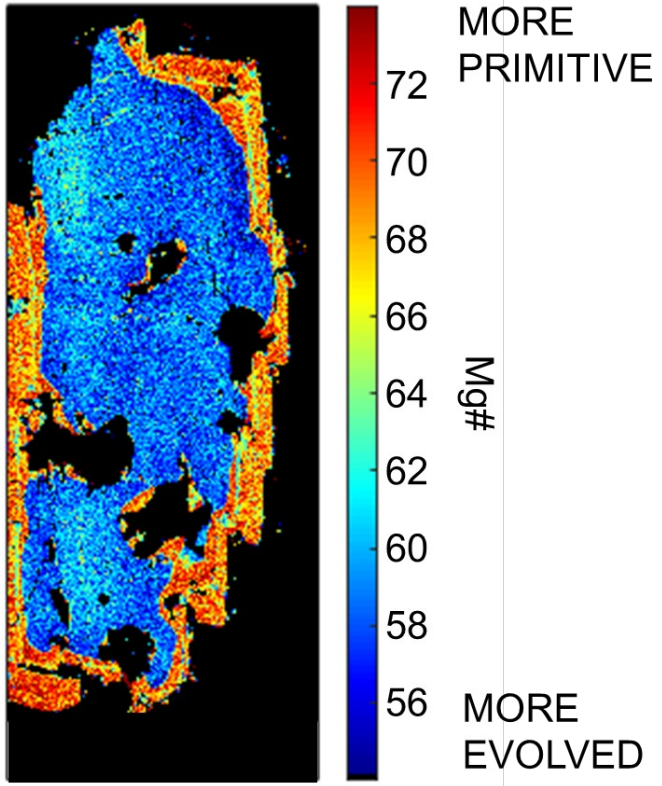


Types of igneous materials for study

Individual Crystals (instruments: EPMA, SEM, SIMS)

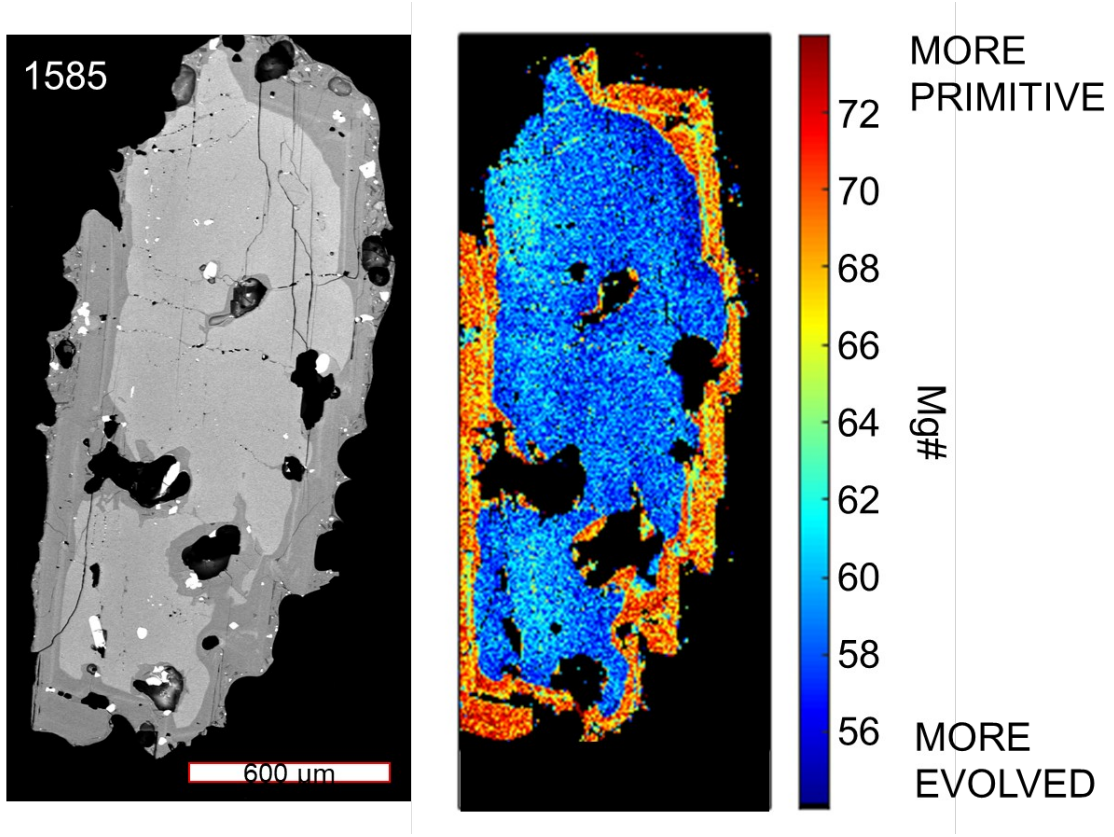






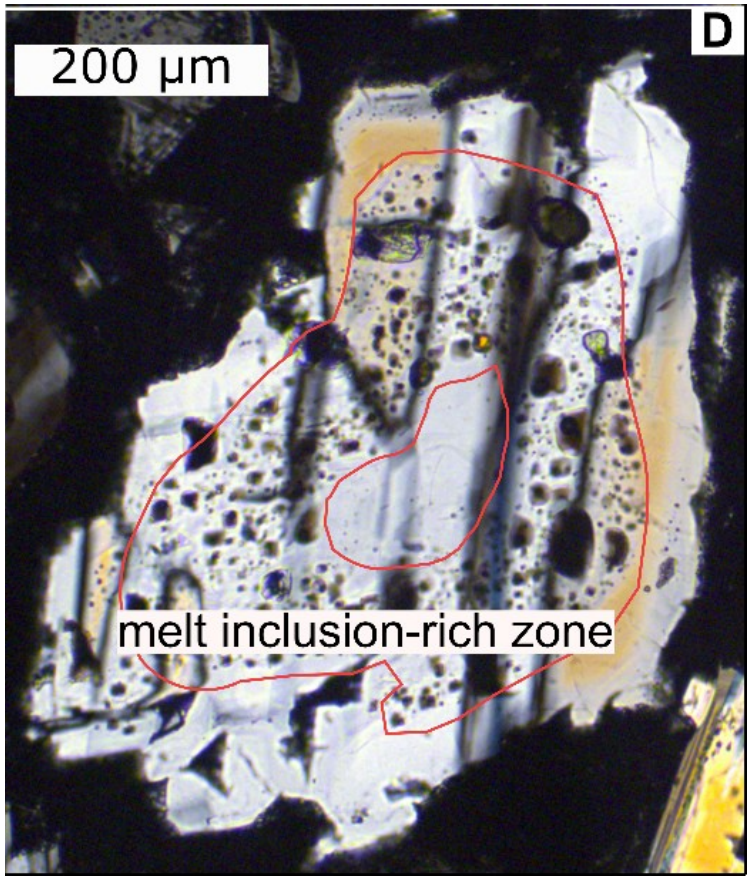
Types of igneous materials for study

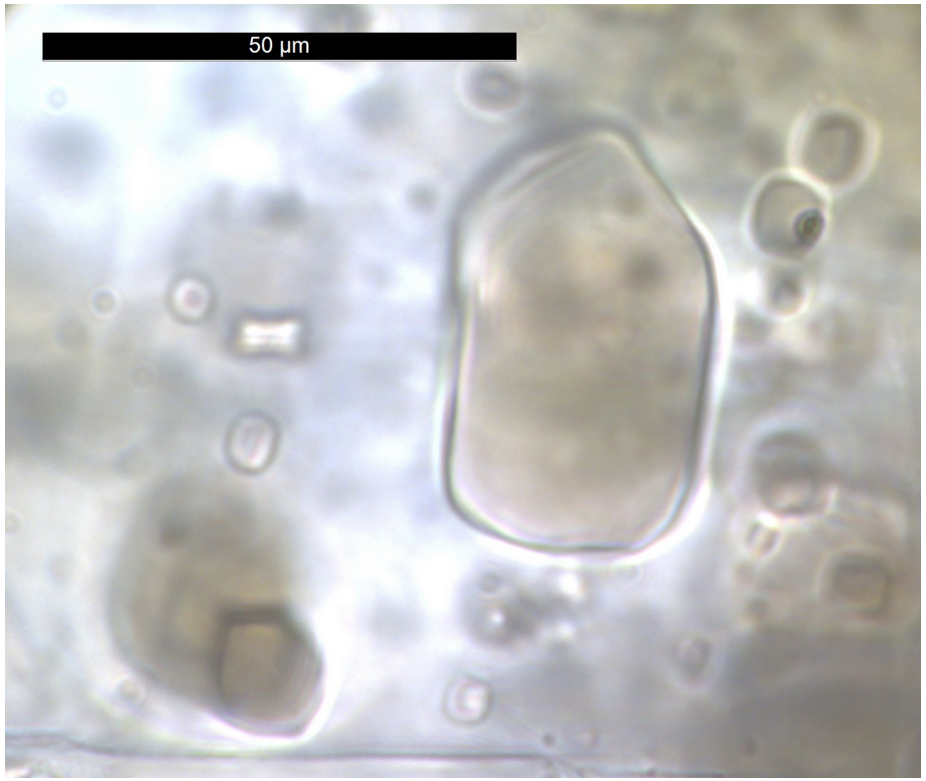
Individual Crystals (instruments: EPMA, SEM, SIMS)



Types of igneous materials for study

Melt inclusions (instruments: EPMA, SEM, SIMS)





Instruments don’t always report 100% totals

Totals aren’t usually 100 wt.% due to things like analytical uncertainty, detection limits, and also loss on ignition (LOI)

LOI is the volatile or hydrous content in a rock and we can measure this by weighing a powdered sample, burning it, and weighing it again:

Initial weight of sample

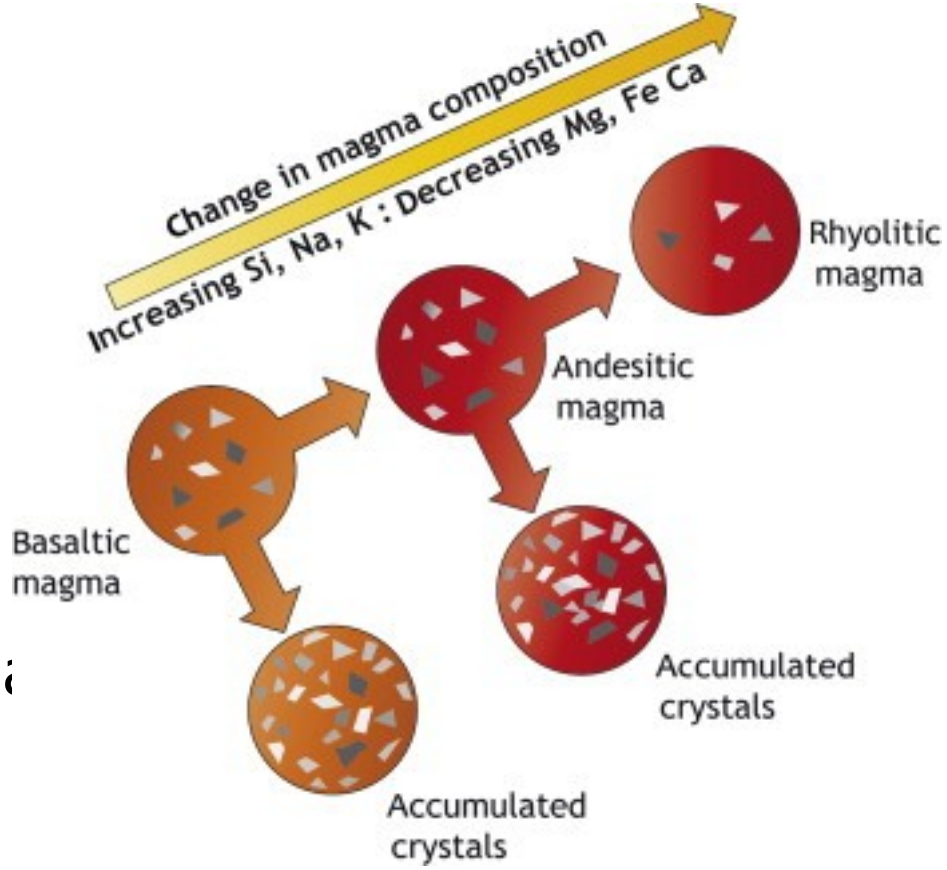
post-furnace weight

$$\mathrm{LOI} = \frac{W_i - W_f}{W_i} \times 100$$

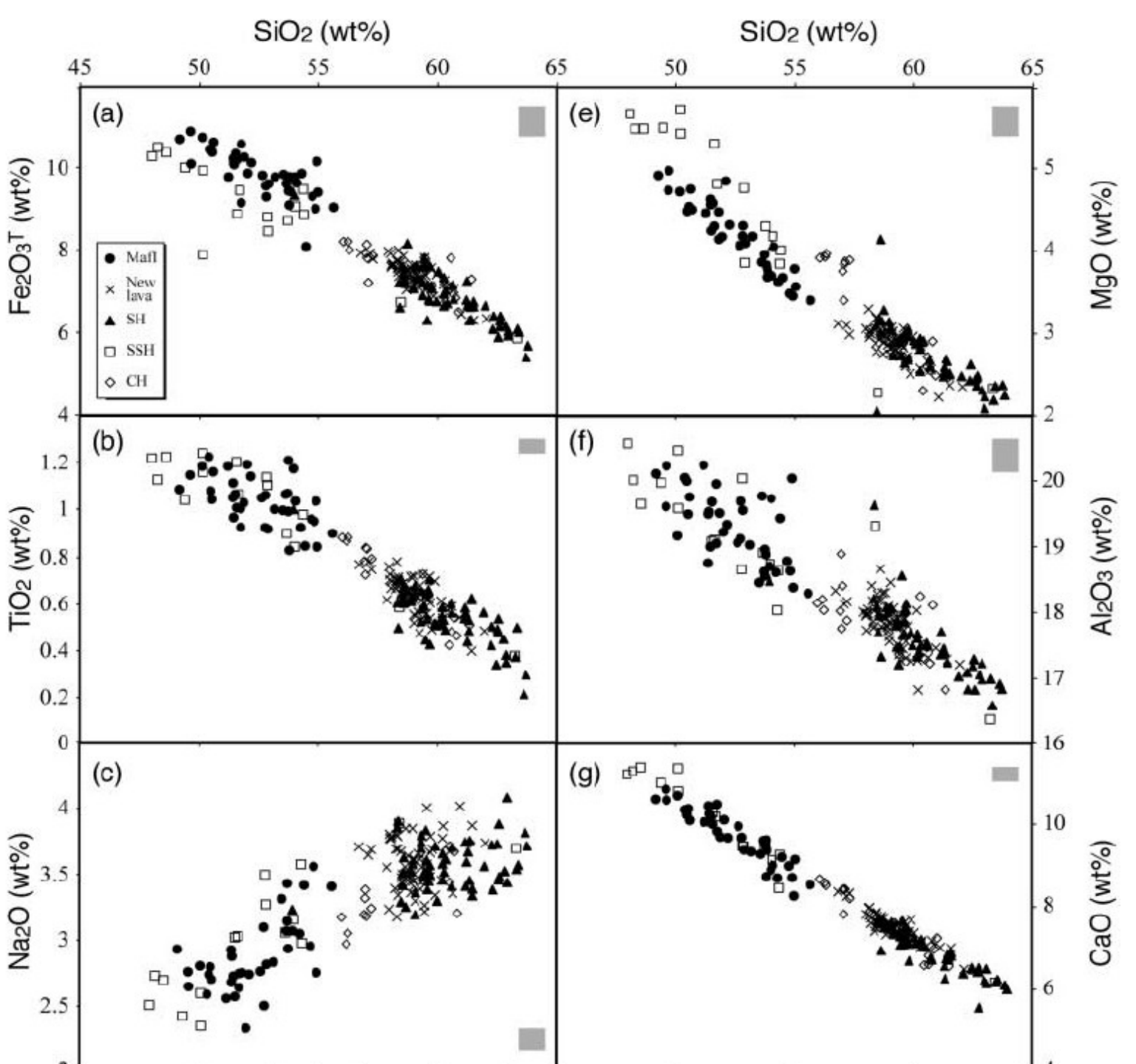
Compatible and Incompatible Elements

- Compatible elements: preferentially incorporated into crystals from cooling melt
- Incompatible elements: stays in melt

- Fractional crystallization:
  - Primitive crystals form first (Bowen's)
  - Differentiation due to density differences
  - Residual melt increase in silica content
  - We can use silica as a MARKER of differentia



Harker Diagrams

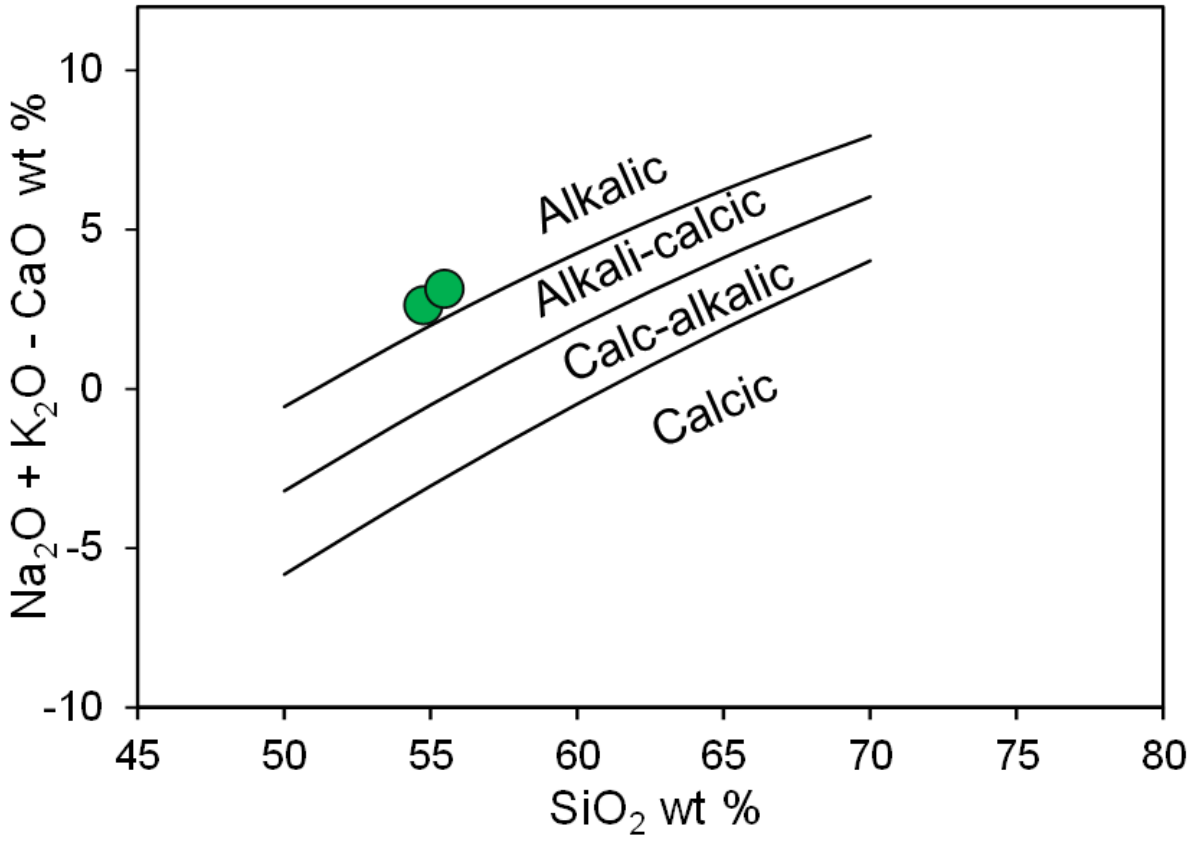


Next Level Groupings
(to reconstruct magma histories)

- Alkali-lime index
- Iron-enrichment index
- Aluminum saturation index
- Alkalinity index
- Feldspathoid Silica-Saturation index

Alkali-Lime Index

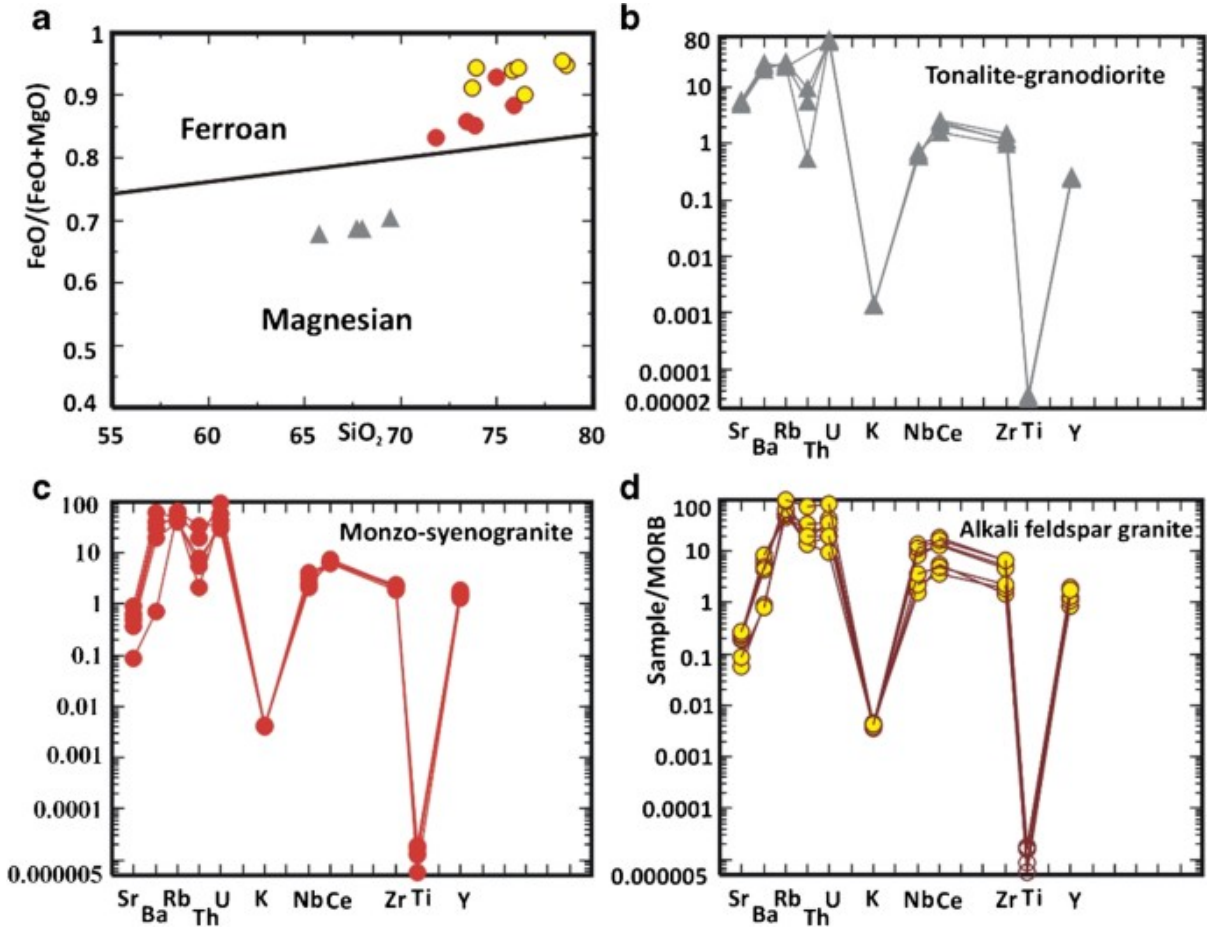
- CaO, Na_2O, K_2O vs. SiO_2
- Harker Diagrams on board
- Four categories:
  - Alkalic (<51 wt. % SiO_2; Cao = Na_2O+K_2O)
  - Alkalic-calcic (51-56 wt. % SiO_2)
  - Calc-alkalic (56-61 wt. % SiO_2)
  - Calcic (>61 wt. % $_{SiO2)}$



(Rakotondravaly & Randrianja, 202

Iron-Enrichment Index

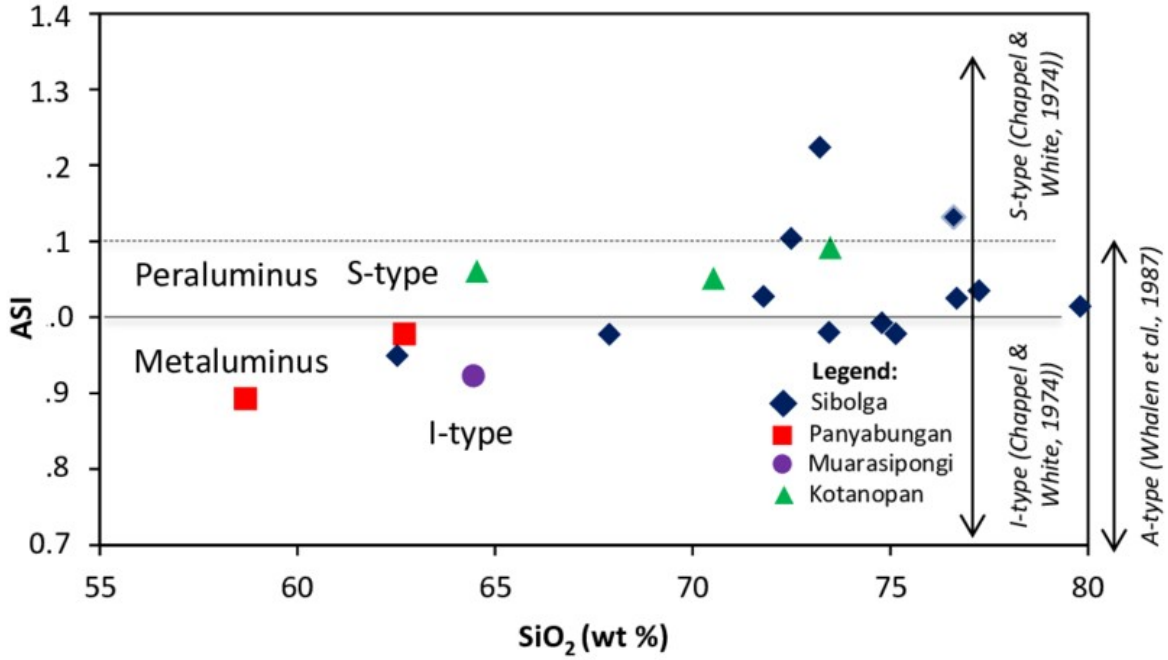
- Ferroan trend – rocks enrich in Fe before alkalis
- Magnesian trend – rocks are under enriched in Fe and replaced by MgO
- Reduced melts typically ferroan
- Oxidized melts typically magnesian
- Harker diagrams on board



(Asran et al., 2021)

Aluminum Saturation Index (ASI or A/CNK)

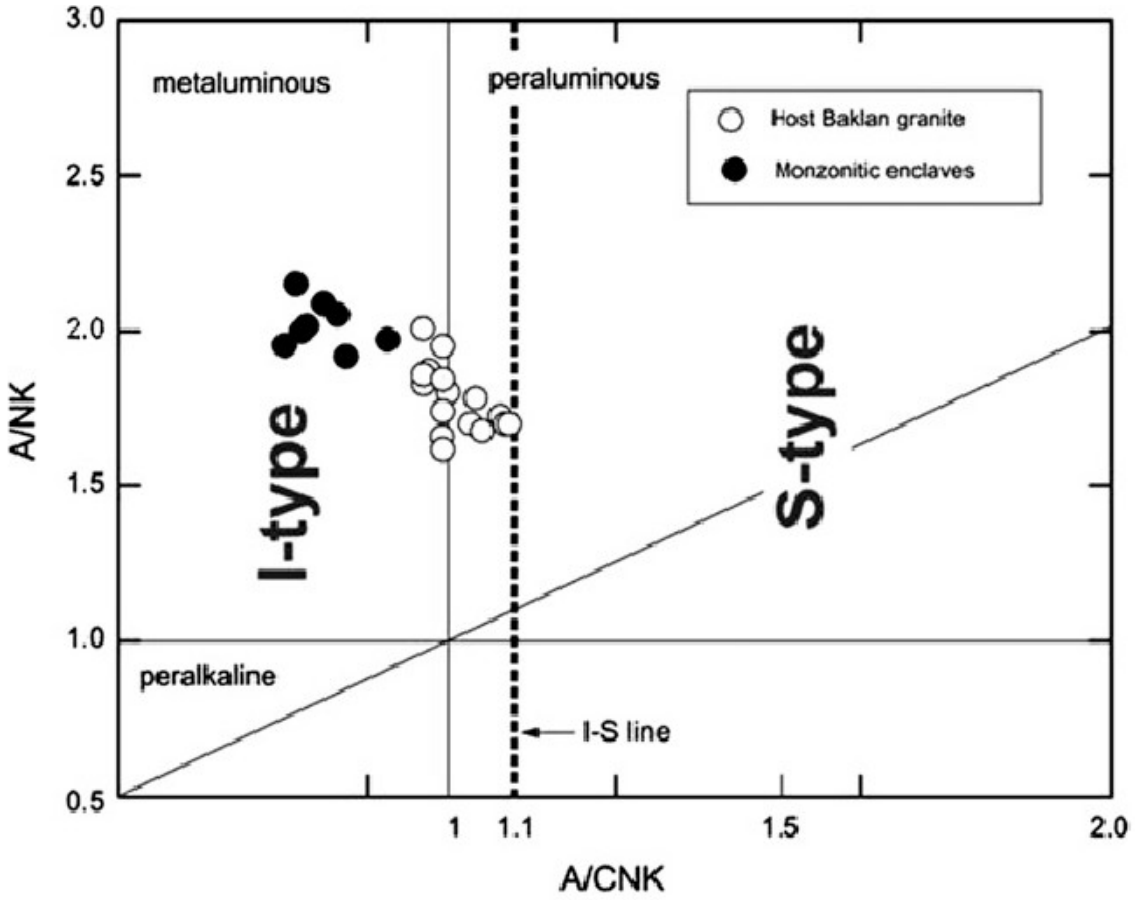
- Feldspars host most Al in rock
- ASI or A/CNK indicates abundance of alkalis (Na + K) over Al
- ASI or A/CNK = [Al/(Ca - 1.67P + Na + K)]
- 3 Groupings
  - Metaluminous ASI >=1
  - Peraluminous ASI <1.1
  - Peralkaline (need ANK…)
- Most helpful for granite petrogenesis



Alkalinity (ANK or AI) Index

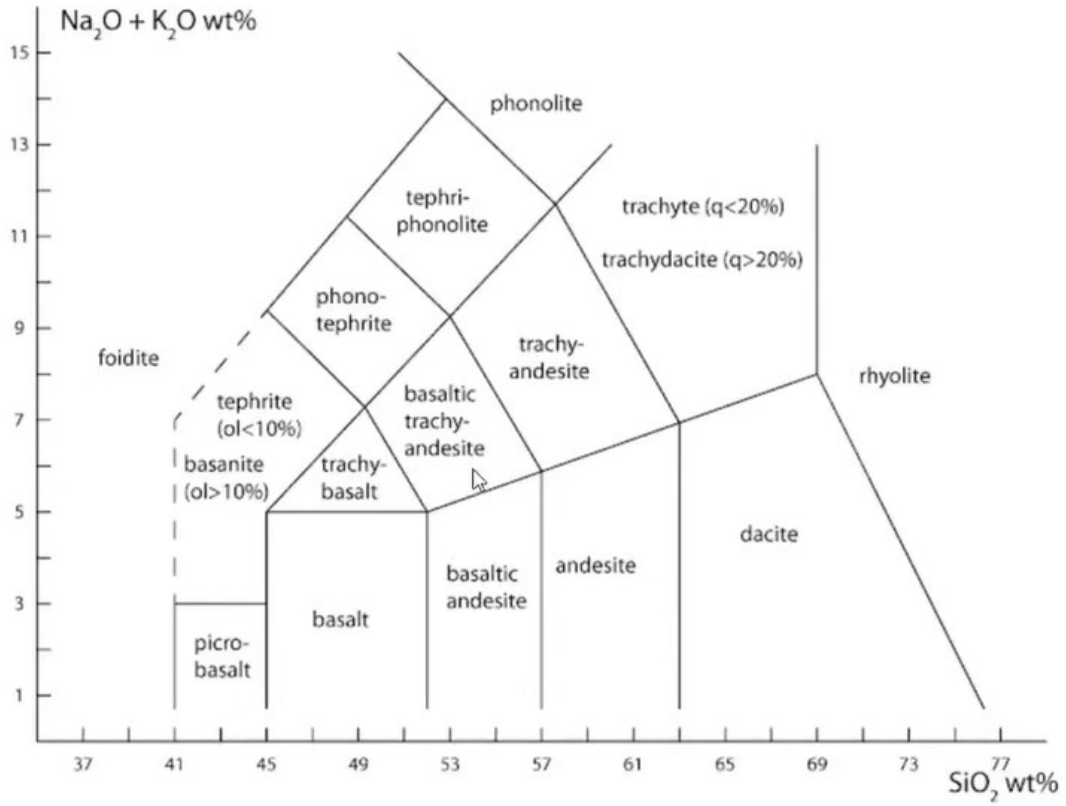
- ANK or AI = [Al – (Na + K)]
  - Metaluminous & Peraliminous ANK > 1.2
  - Peralkaline ANK < 1.2

- Quartz abundance relative to feldspathoids (e.g. leucite & nepheline)
  - Positive for quartz-saturated
  - Negative for silica undersaturated

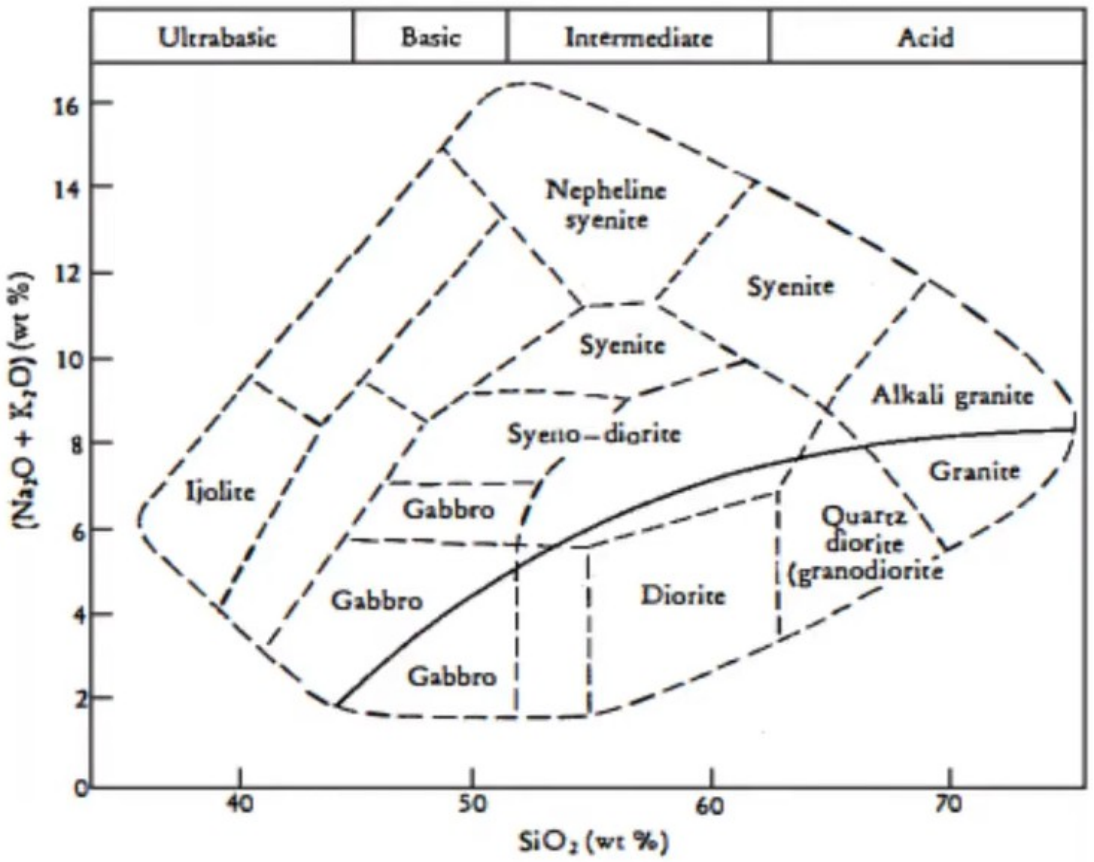


Naming of Rocks – Total Alkali-Silica (TAS)

Le Maitre volcanic TAS diagram



Cox plutonic TAS diagram

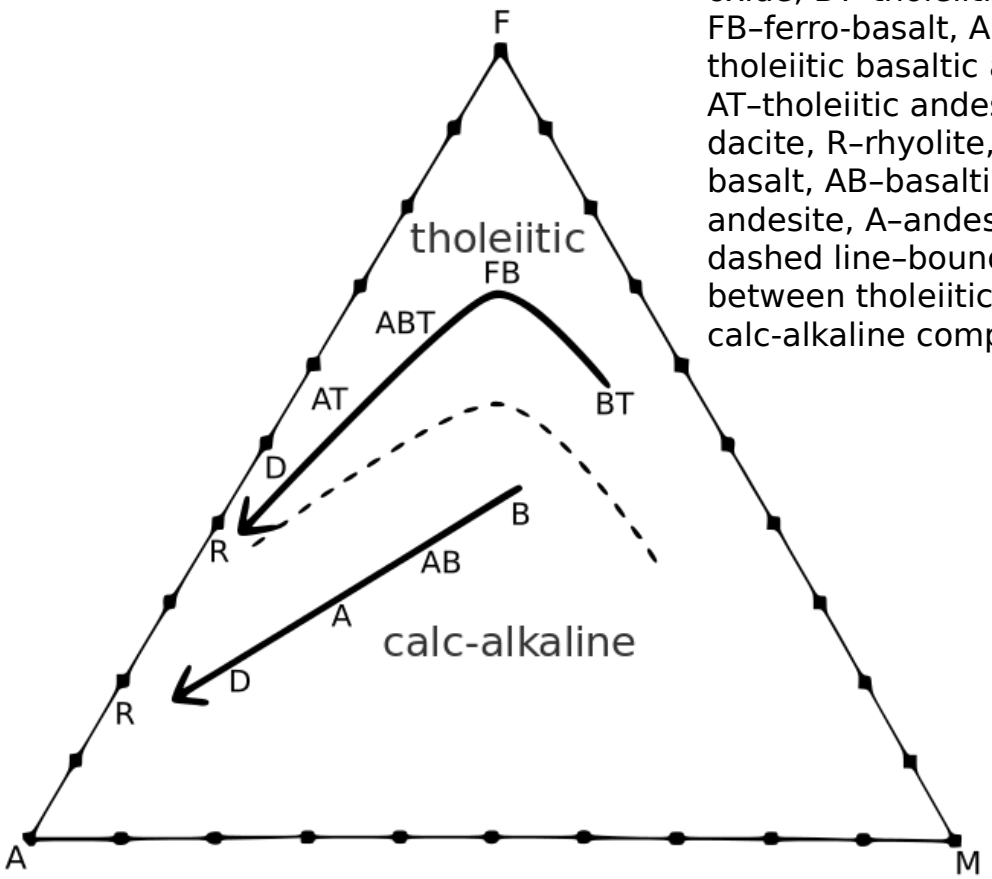


https://www.sandatlas.org/tas-diagram/

Rollinson, H. R. (1993). Using geochemical data: evaluation. *Presentation, Interpretation*, *796*, 317-343.

Tholeiitic and calc-alkaline trends

- Alkali-FeO+Fe2O3-MgO (AFM ternary!)
- Tholeiitic rocks are subalkaine with increase of Fe due to fractionation of Mg-rich minerals (REDUCED magmas)
- Calc-alkaline rocks are subalkaine rocks with decrease of Fe due to precipitation of Fe-rich minerals (OXIDIZED magmas)



A–alkali (sodium and potassium) oxides, F–iron oxides, M–magnesium oxide, BT–tholeiitic basalt, FB–ferro-basalt, ABT–tholeiitic basaltic andesite, AT–tholeiitic andesite, D–dacite, R–rhyolite, B–basalt, AB–basaltic andesite, A–andesite; dashed line–boundary between tholeiitic and calc-alkaline compositions.

Coming up:
Trace elements + intro to thermodynamics and phase diagrams